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Collinear Four-Wave Mixing of Two-Component Matter Waves

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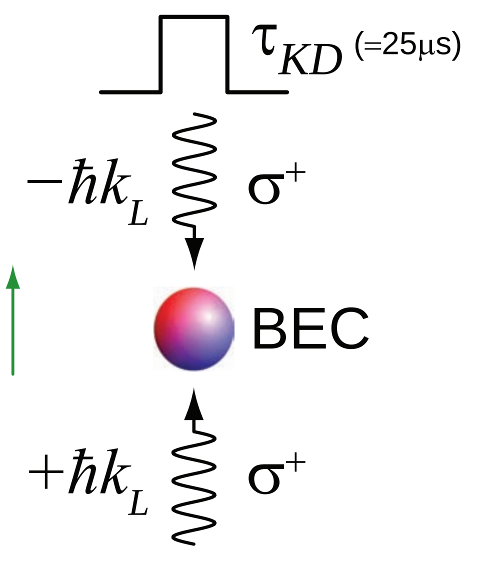
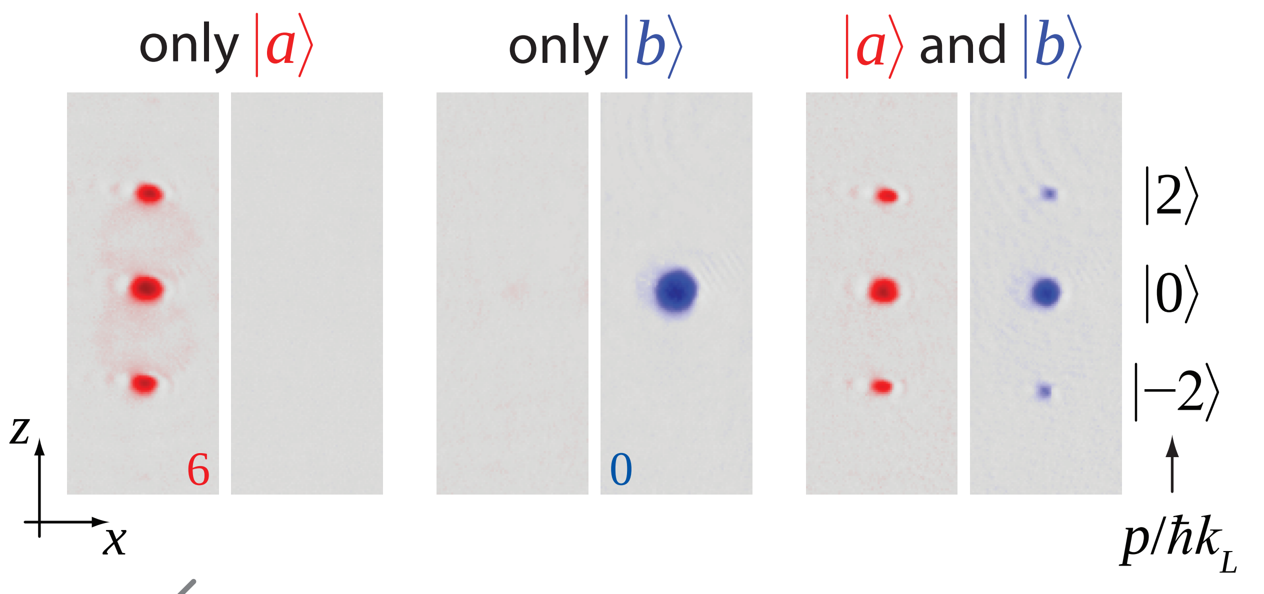
Initial State Prep.



apply state-selective optical lattice pulse onto two-component mixture

(alternative: state-sel. Bragg or Raman)

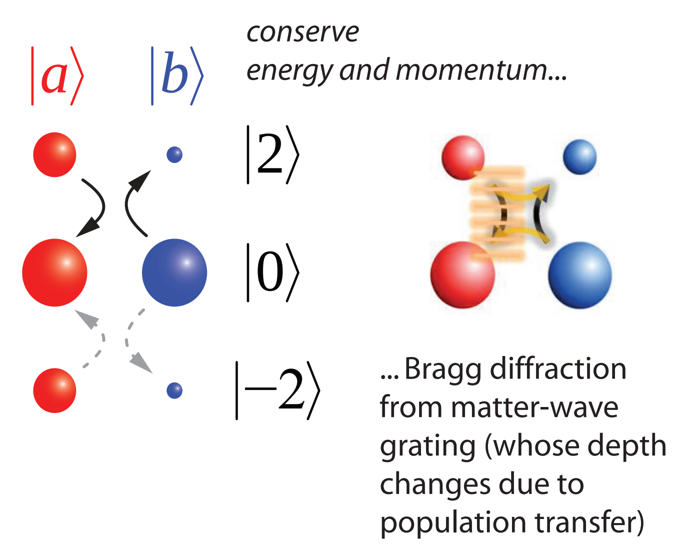
After Release & Time of Flight



on their own, $|b\rangle$ atoms are unaffected, $|a\rangle$ atoms are Kapitza-Dirac diffracted

when both are present, four-wave mixing leads to diffraction of $|b\rangle$ atoms, too

Four-wave Mixing (FWM)



FWM leads to a pairwise redistribution between the momentum modes

Theoretical Description: Coupled-mode Expansion of GPE

$$i\hbar\,\partial_t \Phi_\alpha = \left(-\frac{\hbar^2}{2m}\nabla^2 + V_\alpha + \sum_{\beta\in\{a,b\}} g_{\alpha\beta}\,|\Phi_\beta|^2\right)\Phi_\alpha \qquad \alpha\in\{a,b\}$$

where:

$$V_b = V_{\rm trap}(\mathbf{r},t) \qquad g_{\alpha\beta} = 4\pi\hbar^2 a_{\alpha\beta}/m$$
$$V_a = V_{\rm trap}(\mathbf{r},t) + V_0(t)\,\sin^2(k_L z)$$

mode expansion:

$$\Phi_\alpha(\mathbf{r},t) = \sum_{n=-\infty}^{\infty} c_{n\alpha}(t)\,e^{ink_L z}\,\Phi_0(\mathbf{r}-\hat{\mathbf{z}}\,n v_R t, t)$$

assume Thomas-Fermi form, hydrodynamic expansion (unlike SVEA)

→ for mode amplitudes:

$$i\hbar\,\partial_t a_n = E_R\,n^2 a_n + V_0(t)\left[\tfrac{1}{2}a_n - \tfrac{1}{4}(a_{n+2}+a_{n-2})\right] + \sum_{mm'n'}(g_{aa}\,a^*_m a_{m'} + g_{ab}\,b^*_m b_{m'})\,a_{n'}\,h_{nmm'n'}(t)$$

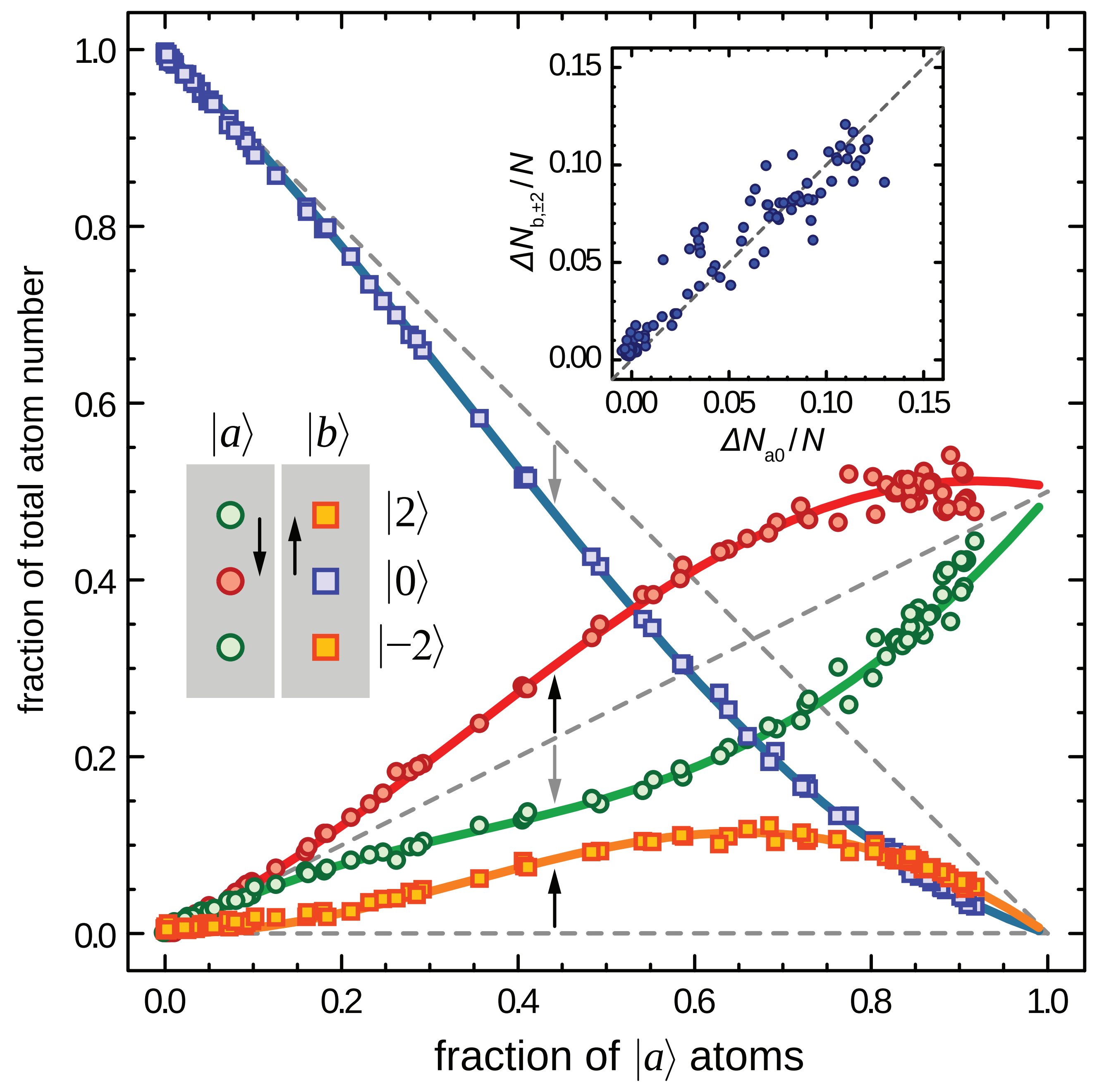
$a_n(t) \equiv c_{na}(t)$, $b_n(t) \equiv c_{nb}(t)$

and similarly for b_n

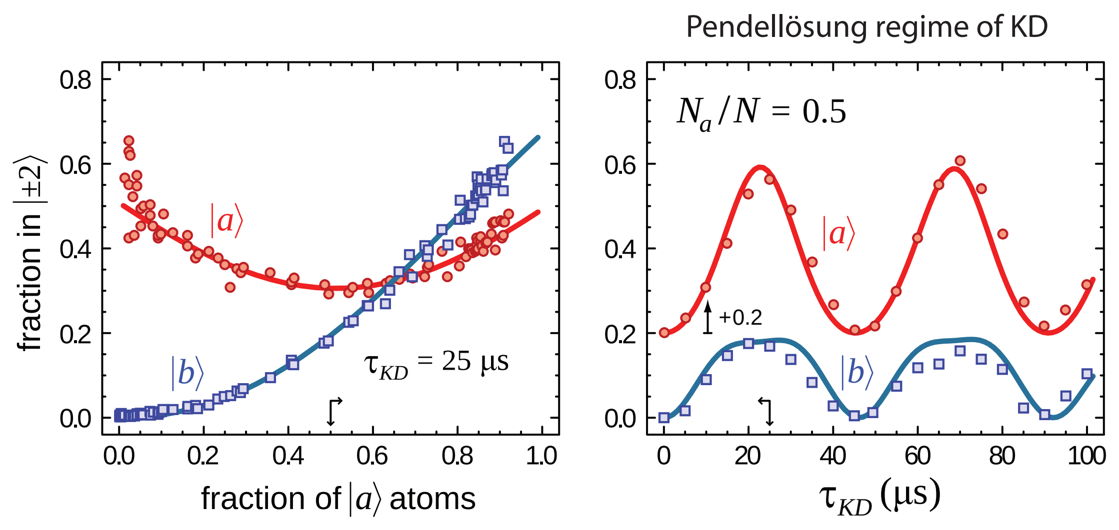
overlap integrals: $h_{nmm'n'}(t) \propto \delta(n+m-m'-n')\,n_{peak}$

decay to zero as wave-packets expand and separate

Mode Populations after FWM depending on initial fraction of each component

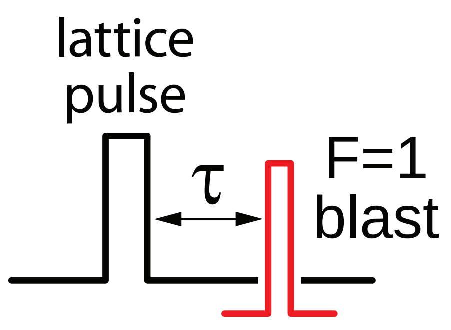


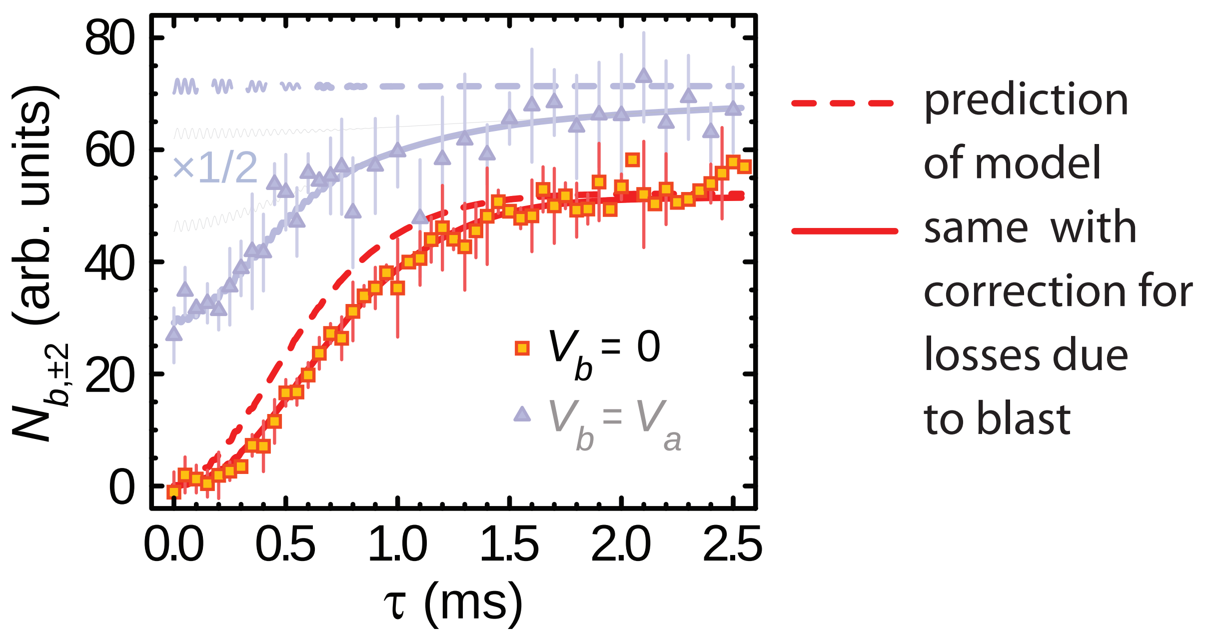
Diffracted fraction per component ("effective lattice depth")



Temporal growth of output mode population

interrupt FWM by selectively removing $|a\rangle$ atoms using resonant light

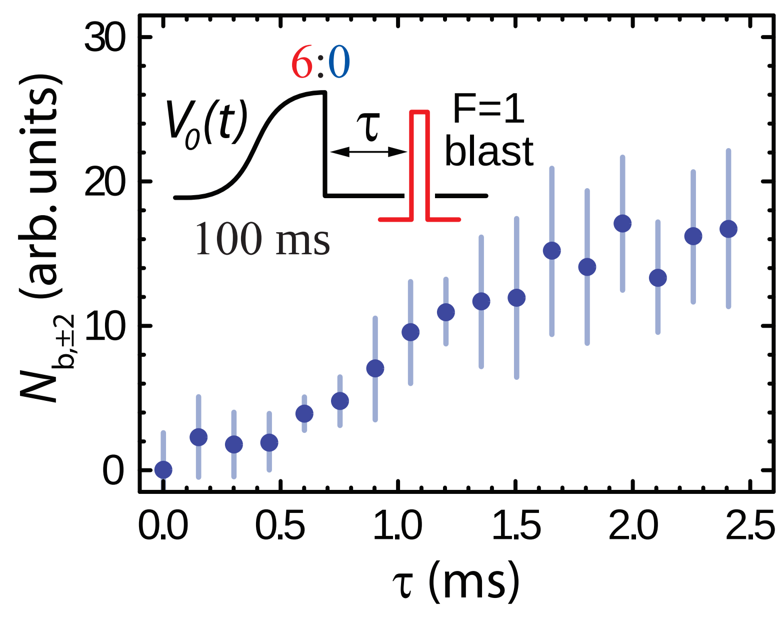


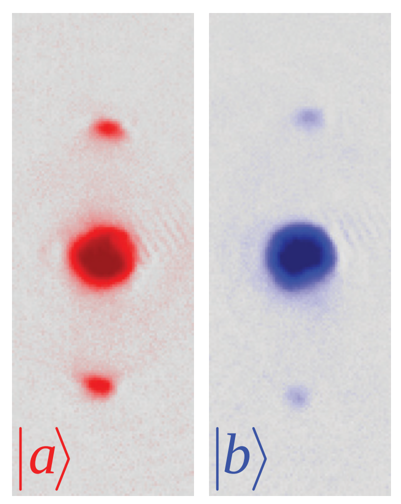


→ model fits temporal evolution of population quite well

Consequences

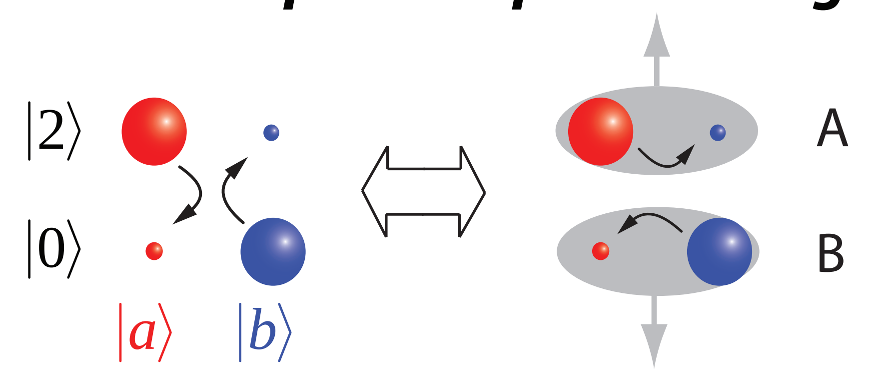
How about an adiabatically ramped up lattice?





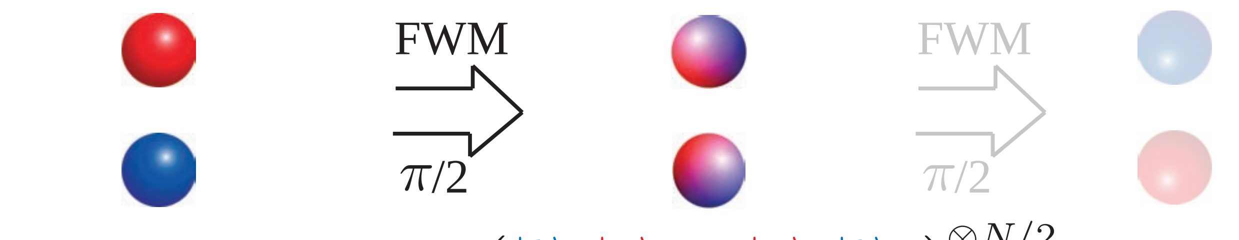
→ FWM can mask/mimic in-situ interaction effects

Coherent pseudospin exchange



conservation of particle number in A and B and of total spin.

Macroscopic spin entanglement



$$|b\rangle_0^{\otimes N/2}|a\rangle_2^{\otimes N/2} \qquad \left(\frac{|b\rangle_0|a\rangle_2 + |a\rangle_0|b\rangle_2}{\sqrt{2}}\right)^{\otimes N/2}$$

(for interaction times longer than currently possible)